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ENERGY ISSUES

Energy Conservation and Efficiency in Giprokoks Designs at Ukrainian Ferrous-Metallurgical Enterprises

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Abstract—Energy conditions at Ukrainian ferrous-metallurgical enterprises are analyzed. Measures to boost energy conservation and energy efficiency are proposed: specifically, the introduction of systems for dry slaking of coke; and steam–gas turbines that employ coke-oven gas or a mixture of gases produced at metallurgical enterprises. Such turbines may be built from Ukrainian components.

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Ferrous-metallurgical enterprises, including coke plants, are major industrial consumers of electrical and thermal energy. The consumption of electrical and thermal energy in the production of 1 t of coke has not changed significantly in recent years; there has even been a slight increase on account of environmental-protection measures.

In 2006, coke plants produced 19.2 million t of coke and consumed ~1.4 billion kW of electrical energy and 4.4 million Gcal of heat.

Given that energy and fuel costs are steadily rising in Ukraine and this trend may be expected to intensify, we can understand the great importance of energy conservation, efficient fuel use, and reduced energy consumption in coke production.

Coke plants are not only large consumers of electrical and thermal energy but also have unused energy potential, in that they produce coke-oven gas and large quantities of heat that are irrationally released to the atmosphere with steam during wet slaking.

In the 1960s, Giprokoks developed a dry-slaking technology permitting the utilization of the heat generated in slaking. Today, 38 such systems operate around the world on the basis of Giprokoks designs or licenses; of these, 22 are in the Commonwealth of Independent States. In Ukraine, four dry-slaking units operate at OAO Avdeevskii Koksokhimicheskii Zavod; another went into operation at OAO Alchevskkoks in 2007. The slaking process is as follows: gas at 150–170°C that is circulating in a closed loop (from the slaking chamber to the waste-heat boiler and back) is sent by a fan to the slaking chamber, where it is heated, with cooling of the coke to 750–800°C. It is then sent to the waste-heat boiler, where it is cooled and generates energy-grade steam.

This process has the following benefits over wet slaking:

—it permits utilization of the heat from the hot coke: up to 50% of that consumed in coking;

—it improves the moisture content, strength, and reactivity of the metallurgical coke, with accompanying decrease in blast-furnace coke consumption by 3–5%;

—it increases blast-furnace productivity;

—it minimizes noxious atmospheric emissions.

The dry slaking of 1 t of coke produces 0.5 t/h of energy-grade steam (or 0.3 Gcal of heat). Thus, in slaking coke for a coke battery of productivity 900000 t/yr, the quantity of steam generated by the waste-heat boilers of the dry-slaking unit is ~50 t/h (30 Gcal).

In addition, for the main consumers of steam and for in-plant heating and other uses, steam with $p = 0.6$ MPa and $t = 250°C$ is required. Therefore, in installing a counterpressure turbogenerator, ~5.5 MW-h of electric power may be generated for thermal purposes.

Thus, on the assumption that dry slaking of all the coke is possible, the total quantity of heat generated would be ~5 million Gcal/yr, and the power generated would be ~0.93 billion kW-h/yr. This would completely meet the plant's demand for thermal energy and provide 70% of its electric power.

Presently, around 18% of coke is dry-slaked in Ukraine. According to our calculations, on the assumption that dry-slaking systems are included in the general plan for coke-battery reconstruction and relining, ~60–70% of coke may be dry-slaked.

Giprokoks has developed the working design for the dry-slaking machine at OAO Alchevskkoks coke battery 10A and also the working design for the dry-slaking machine at OAO Zaporozhkoks battery 1A. Technical workups have been completed for the inclusion of dry-

slaking systems in the general plan for coke batteries 5–8 at OAO Alchevskkoks, batteries 5–6 at OAO Bagleikoks, and batteries 7–8 in the coke plant at OAO Arcelor Mittal Krivoi Rog. The feasibility of constructing dry-slaking systems at coke batteries 1 and 3–4 in the coke plant at OAO Azovstal is currently undergoing cost–benefit analysis.

Interest in coke-oven gas as a possible replacement for natural gas is rising as natural gas becomes more expensive. The calorific value of coke-oven gas is about half that of natural gas. In Ukraine, coke plants do not use natural gas, but metallurgical plants consume considerable quantities. Therefore, there is great interest in coke-oven gas.

In 2006, 8.3 billion m^3 of coke-oven gas was produced; around 50% was used in coke-battery heating, while 1.8 billion m^3 was used in heating coke-plant boilers, 1.9 billion m^3 was sent to metallurgical enterprises, and 243 billion m^3 was wasted.

As we see, half of the coke-oven gas produced is burned at coke plants in boilers for heating and power generation. The steam produced is used in production processes and in heating. This heat is used to generate electric power at only four coke plants (475 million kW in 2006).

However, the efficiency of the boilers in which coke-oven gas is burned is no more than 85–87%. The old and outdated boilers prevent complete utilization of the potential of coke-oven gas. The efficiency of fuel use in boilers and power plants is extremely low.

The upgrading of energy systems must include not only the replacement of old and outdated equipment (boilers, turbines, etc.) but also the generation of steam and electric power by more effective technologies–for example, steam–gas turbine systems operating in a cogeneration cycle, which have recently been widely introduced in the power industry. The energy efficiency of such units is 50–55%, while the fuel efficiency is –80%.

Steam–gas turbine systems consist of a gas-turbine engine, together with an electrical generator, an air compressor, and a combustion chamber; a steam-driven waste-heat boiler with a booster heater; a high-power compressor for blast-furnace gas; and a steam turbine with an electrical generator.

In 2006 and 2007, Giprokoks developed a commercial proposal for the construction of a steam–gas turbine system running on coke-oven gas, on the basis of GP Zora (Mashproekt, Nikolaev) gas-turbine engines, for OAO Avdeevskii Koksokhimicheskii Zavod, OAO Bagleikoks, OAO Arcelor Mittal Steel Krivoi Rog, and ZAO Makeevkoks. The time to recoup the investment in these projects is 1.1–1.6 yr.

The construction of a PGTU-150 steam–gas turbine system running on blast-furnace gas and coke-oven gas has been proposed for OAO Azovstal and OAO Arcelor Mittal Steel Krivoi Rog.

As a demonstration project, Giprokoks proposed the PGTU-150 steam–gas turbine system, in the form of two modules: a gas-turbine unit; and a steam-turbine unit. The gas turbine unit consists of a gas-turbine engine, with a generator and a compressor of blast-furnace gas on a single shaft; a high-power compressor of coke-oven gas; an electrofilter; and a gas-cooling unit. The steam-turbine unit consists of a waste-heat boiler, a steam-condensation turbine, and a deaeration and feeder system.

The basic fuel is blast-furnace gas, with small additions of coke-oven gas to maintain constant calorific value of the mixture at ~1050 kcal/m^3.

The operating principle is as follows. Blast-furnace gas, after preliminary dust removal in an electrofilter, is sent to the compressor and then directly to the combustion chamber of the gas-turbine engine. The coke-oven gas, after passing through the high-power compressor, is also sent to the combustion chamber. The combustion products turn the shaft of the gas-turbine unit.

The spent gas at ~450°C from the turbine of the gas-turbine unit is sent to the waste-heat boiler. To ensure the necessary steam heating and increase the steam productivity of the boiler, the boiler heater includes a booster heater fueled by the blast-furnace gas that is not burned in the gas-turbine engine, with small additions of coke-oven gas.

The steam generated in the waste-heat boiler is sent to the turbogenerator to produce electricity.

The steam that condenses in the turbine's condenser is pumped to the deaerator and hence supplied to the waste-heat boiler.

The PGTU-150 system may operate in the standard mode (with the booster heater), with combustion of all the blast-furnace gas; in waste-heat mode (without the booster heater); and in autonomous mode (without the gas-turbine unit). An injection fan supplies air for fuel combustion. When the waste-heat boiler is shut down, the gas-turbine unit may also operate through a bypass gas line.

Startup of the gas-turbine unit is by means of the generator in motor mode, with power supply from an ac grid through a frequency converter. At the specified turbine speed, coke-oven gas is supplied to the combustion chamber and is ignited by a plasma-ignition system in the air within the compressor. The hot gases formed turn the turbine of the motor, along with the generator and the compressor of blast-furnace gas. With increase in turbine speed to a particular value, blast-furnace gas is supplied through a second channel to the combustion chamber. In all conditions of turbine-engine operation, the control system maintains the ratio of blast-furnace gas and coke-oven gas specified by the program.

Startup of the steam-turbine unit is the result of startup of the waste-heat boiler in autonomous mode, with subsequent startup of the steam-driven turbogenerator. Simultaneous startup of the gas-turbine unit and steam-

turbine unit is possible. This reduces the time required to attain the rated conditions.

As already noted, the basic component of the PGTU-150 system is a gas-turbine engine. One of the world's most up-to-date designs for the power industry is selected. The engine incorporates the best aspects of power-industry, marine, and aviation gas turbines and is based on design approaches, materials, and technologies that have been tested by many years of experience in four generations of gas-turbine engines produced by Zorya-Mashproekt design enterprise. This is the world's first power-industry engine produced on the basis of gas-turbine technology, in contrast to foreign designs based on steam-turbine technology. The new approach to the development of power-industry gas-turbine engines has a number of benefits:

—reduced metal consumption (by a factor of 2–3), thanks to the use of higher-quality materials and modern design and production technologies;

—high maneuverability;

—efficiency that matches its most advanced counterparts;

—ease of repair, thanks to modular design and ready access to the most-stressed components;

—reliability and longevity, thanks to effective protection of the metal from the effects of high temperature.

The coke-oven gas is compressed by means of a state-of-the-art fifteen-stage air compressor with moderate compression, which is designed for binary steam–gas systems. The compressor includes a controllable input guide system so as to ensure optimal operation in changing conditions.

The counterflow combustion chamber has no counterpart. The diffusional central zone includes sprayers for coke-oven gas; the homogeneous peripheral zone is intended for the combustion of blast-furnace gas after preliminary dilution with air. All the components of the combustion chamber are made of high-temperature alloys.

The reactive four-stage gas turbine includes a unique blade system. The external surface of the blades is perforated, and internal channels are formed on casting. Air supplied from the compressor to the channels in the blades ensures cooling. A complex anticorrosional and thermally insulating metal–ceramic coating is applied to the blades.

Before combustion, the blast-furnace gas must be compressed. For this purpose, a compressor has been developed by Zorya-Mashproekt design enterprise (Nikolaev) on the basis of the compressor in the mass-produced 25-MW UGT25000 motor. Hot steam is generated by a waste-heat boiler operating with the PGTU-150 system. This boiler is designed to operate on the waste gases of the gas-turbine engine in all operating conditions. The design parameters of the waste-heat boiler are as follows:

Ambient temperature, °C	+15
Gas consumption, kg/s	445
Gas temperature, °C	450
Maximum consumption of coke-oven gas at gas-turbine unit, m^3/h	29280
Maximum consumption of blast-furnace gas in gas-turbine unit, m^3/h	240830

The following options are available for boiler operation: waste-heat mode (without the booster heater); standard mode (with the booster heater); or autonomous mode (with the gas-turbine switched off).

The booster heater operates with a mixture of blast-furnace gas and coke-oven gas of total calorific value ~1050 kcal/m^3. In boiler operation with the booster heater, oxygen in the waste gases from the gas-turbine engine is used for combustion. In autonomous mode, a fan is used. The waste-heat boiler is of drum type, with natural circulation, and is designed for outdoor locations under an awning.

The Siemens SST-600 turbogenerator is used as the steam-condensation turbogenerator. The turbine employs standard tested modular components. The modular design ensures that the turbine is reliable and also provides greater scope for the design of effective flow-through sections. The turbine is characterized by a reactive blade configuration, low steam consumption, and great operational efficiency.

The turbine cylinder is made of alloy steel, whose composition corresponds to the operational parameters of the steam. The flow-through section of the turbine is custom-designed for the customer, by adjusting the number of stages and their characteristics.

The turbine unit is equipped with a condensation system that ensures condensation of the outgoing steam.

The turbine may also be supplied with a system for condensing the outgoing steam, removing the uncondensed gases, and returning the condensate to the water feed to the boiler.

The design for the PGTU-1500 unit developed by Giprokoks represents a new approach to the power-generation system at metallurgical-coke plants. Such units will help to take coke-plant power systems to a new level. The PGTU-1500 system, which is based on Ukrainian components, is entirely competitive with its imported counterparts and provides a reliable source of inexpensive high-performance steam and inexpensive electric power. The integrated generation of steam and electric power may greatly improve coke-plant power systems.

However, despite the many benefits of steam–gas turbine systems, their introduction in ferrous metallurgy has been postponed for various reasons—in particular, the large capital expenditure required; plant managers who are inadequately informed regarding this technology; and certain logistical problems.